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THE REDUNDANCY OF SCHEDULED AND UNSCHEDULED MAINTENANCE,(U)

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September 1979

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I. K. Cohen, T. S. Donaldson, T. M. Rodriguez

A Rand Note

prepared for the

United States Air Force

Rand
SANTA MONICA, CA. 90406

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This Note concerns the extent to which aircraft scheduled and unscheduled maintenance are redundant. It investigates the extent to which Periodic Inspection items on the F-4 aircraft are made visible at the flight line during unscheduled aircraft maintenance. The study focuses on inspection tasks behind aircraft doors, and assumes that once a door is removed for maintenance activity, the inspection item is visible. Visibility or accessibility for condition monitoring is defined as the frequency of door removals. The total number of removals for each aircraft door was counted, and a probability model was used to estimate the probability that a door would be opened within a given inspection interval. The results of this study indicate that most of the F-4 Periodic Inspection tasks are accessible for condition monitoring on the flight line during unscheduled aircraft maintenance. The Note discusses the implications of these results for inspection policy. (Author)

PREFACE

Elements of the Air Force have made considerable progress in reducing the frequency and content of aircraft scheduled inspections. Nevertheless, this kind of maintenance continues to detract from sortie production. But if scheduled inspection requirements are reduced, a natural concern arises that one is running an unknown but undesirable amount of risk.

Empirical evidence on scheduled maintenance, assembled at Rand over many years, indicates that despite large extensions in aircraft inspection intervals (planned or otherwise), no apparent degradation in operational capability has resulted. One possible explanation of this finding is that scheduled maintenance, as currently practiced, is simply unnecessary. Other explanations, however, are also possible. One, for example, concerns the kind and amount of *maintenance redundancy*. Evidence indicates that there is indeed redundancy between depot and base-level inspection of aircraft. With this duplication of effort, aircraft continue to be "protected" even if the inspection interval is extended and the content is reduced for either depot or base. Parenthetically, it should be noted that the Air Force is taking steps to deal with this kind of redundancy.

There may, however, be another kind of maintenance redundancy--a point that may help explain why large interval extensions and content reductions do not degrade operational capability. This second kind of redundancy springs from the fact that in the course of doing unscheduled maintenance on the flight line, "all" areas of the aircraft that are of concern in scheduled maintenance over time become visible to maintenance personnel. Personnel performing unscheduled maintenance informally "look around," in effect performing the inspection portion of scheduled maintenance. In the course of this unscheduled maintenance, other required scheduled maintenance tasks such as servicing, testing, calibration, and replacement may be performed. In considering this kind of redundancy, one may hypothesize that unscheduled maintenance

within a given area of the aircraft is at least as frequent as the scheduled maintenance itself.

In this Note we dub the ability of maintenance personnel to "look around," whether by eyeball or some other means, as "condition monitoring."* The Note attempts to empirically determine the extent of the *opportunity* offered to maintenance personnel doing unscheduled maintenance on the flight line to provide condition monitoring, at the appropriate frequencies, of those portions of the aircraft receiving scheduled maintenance.

The contents of this Note were initially circulated in August 1978 as a working document. Publication as a Note (with minor editorial revisions) should permit access to a wider audience. The work was done under the Project AIR FORCE project "Operations and Readiness Improvements Program: Concept Development and Project Formulation."

The Note should be of interest to those elements of the Air Force concerned with the establishment and implementation of scheduled maintenance policies and procedures. *Readers not interested* in the technical details may wish to read only the Summary, Sec. I ("Introduction"), Sec. III ("Summary of Results"), and Sec. IV ("Conclusions"), the last of which discusses implications for action.

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*Actually, the term "condition monitoring" has been extended to mean doing the scheduled maintenance tasks of servicing, calibration, and replacement in addition to inspection and testing tasks. See p. 1, below.

SUMMARY

The purpose of this study is to determine the extent to which Periodic Inspection items on the F-4 aircraft are made visible (accessible for inspection or condition monitoring) at the flight line during unscheduled maintenance, or during flight line inspections.* The study does not address the issue of the relationship between exposure of an inspection item and the actual occurrence of an inspection, which would require that the correct specialist is working in the area and attends to the inspection item.

The purpose of aircraft inspections is to assure air and mission worthiness; however, this intended benefit has both direct and indirect costs associated with it. Aside from the direct manpower costs and loss of aircraft availability, there are known to be a number of negative and costly effects of inspection. Loss of aircraft availability is considerably higher than commonly understood, because of excessive scheduled nonflying before and after the actual scheduled inspection periods. In addition, studies have shown that aircraft reliability is actually decreased on sorties immediately following inspections. It has also been observed that, even when dramatic changes in base and depot inspection interval and content occurred that were not consistent with intended policy, no observable degradations in aircraft performance were noted.

The major hypothesis of this study is that the above kinds of findings result from the redundancy between scheduled and unscheduled maintenance. Under this hypothesis, items requiring inspection at certain intervals in scheduled maintenance become visible for condition monitoring by maintenance personnel at adequate frequencies in the course of unscheduled maintenance and flight line inspections. We have observed that this redundance is not generally taken into account in establishing periodic inspection content and intervals.

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*Some periodic inspection items are visible because of pre- and post-sortie inspection, and although these have a small effect on unscheduled visibility, the two are combined in results. It made no sense to exclude these items when their visibility at the flight line was so high.

This study focuses on inspection tasks behind F-4 aircraft doors, and assumes that once a door is removed for maintenance activity the inspection item is visible. Visibility or accessibility for condition monitoring is defined as the frequency of door removals.

A first study to determine the extent of accessibility for condition monitoring was based on a sample of 189 F-4 aircraft over 18 months using AFM-66-1 maintenance data. A number of uncertainties about the data led to a second and smaller study utilizing both AFM 66-1 maintenance data and the Aircraft Flight Data Record (AFTO Form 781). The first study included aircraft series F-4C, D, and E, while the second contained only the D.

In each study the total number of removals (hits) for each aircraft door was counted for all aircraft, and a probability model was used to estimate the probability that a door would be opened within a given inspection interval (in this case the 600-hour Periodic and the 300-hour postflight).

The second study found that the data uncertainties in the first study were not serious. The C and D aircraft were found to have approximately equal failure rates, and both were substantially higher than those of the E; therefore, the analysis combined the C and D series and treated the E separately.

Results indicate that, for the F-4C and D aircraft, most inspection items were visible during unscheduled maintenance; 33 of the 81 Periodic Inspection doors studied were opened every time a sortie was flown, because of flight line inspection requirements. In both studies 59 doors (73%) had probabilities equal to or greater than 0.99 of being opened in the 600-hour interval, and only 15 (19%) in both studies, and 21 (26%) in either study had less than a 0.95 chance of being opened in 600 hours. In the case of the F4-E, 36 doors (47%) had a probability of being opened in a 600-hour interval, and 19 (38%) had a probabilty of less than 0.95 of being opened in the interval. The E series aircraft has somewhat less visibility on inspection tasks than do the C and D series.

The results of this study indicate that many of the F-4 Periodic Inspection tasks are accessible for condition monitoring on the flight

line, although the data do not indicate the extent to which maintenance personnel actually used the opportunity to perform the condition monitoring. These results indicate several possible courses of action:

1. Encourage an explicit program of condition monitoring on the flight line. Following such implementation, set up a system for accomplishing some ("all") scheduled inspection tasks in connection with flight line maintenance. This may require modification of existing data systems to facilitate simplified tracking mechanisms to assure adherence to scheduled inspection requirements. Continued need for inspection dockings for inspections that are not susceptible to condition monitoring by maintenance personnel may be necessary.
2. Include, in protocols used for judging scheduled maintenance requirements, the recognition that maintenance is able to detect "failure resistance" not only in "scheduled inspections" but also in unscheduled maintenance when the aircraft is in various states of disassembly.
3. Recognize that the contribution that flight line maintenance can add to the monitoring of aircraft condition can reduce the risks in extending inspection intervals and decreasing inspection content policy changes. Thus, decisionmakers have additional supportive reasons when faced with proposals for inspection interval extension and content reduction.
4. Explore procedures for using the visibility phenomenon within the context of the Production Oriented Maintenance Organization (POMO), because this type of organization appears to be well suited for implementing policies of condition monitoring on the flight line. This is likely to be so because of the role of Crew Chiefs and the proximity of specialists to the aircraft under POMO.
5. Extend this F-4 analysis to other aircraft types, and explore the use of the approach discussed in helping to determine depot level inspection requirements.

ACKNOWLEDGMENTS

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The authors are also grateful to Eugene C. Poggio for developing the probability model and to Gail Halverson for computer programming.

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CONTENTS

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I. INTRODUCTION

This study investigates the extent to which scheduled maintenance requirements are potentially satisfied during unscheduled maintenance. Specifically, we determine the degree to which F-4 aircraft Periodic Inspection items are made visible when aircraft are disassembled by flight line personnel for unscheduled maintenance and inspection (pre- or post-flight, etc.).[*] By "visible," we mean that items requiring scheduled maintenance are accessible for condition monitoring[†] by maintenance personnel. This does not mean that the items *are* condition monitored, although in some cases it would be difficult not to do so. Neither does it imply that the correct specialist or skilled person is working in the area of interest so that the appropriate scheduled maintenance might be performed. These issues are addressed in Sec. IV, "Conclusions."

Aircraft-scheduled inspections are intended to assure air and mission worthiness, but this intended benefit does not come without its costs. In addition to the obvious direct costs associated with the use of manpower and loss of aircraft availability in scheduled maintenance, considerable information has been assembled regarding negative side-effects of scheduled maintenance.[‡]

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[*] Though not singled out for explicit attention here, it might be that the Periodic Inspection item became visible *because* that was the item being worked on in unscheduled maintenance. Furthermore, the unscheduled maintenance might have required servicing, inspection, testing, and/or replacement that might be redundantly required in scheduled maintenance.

[†] In principle, scheduled maintenance may include servicing, inspection, testing, calibration, and replacement. Also in principle, the term "condition monitoring" is not restricted to eyeball alone. No specific monitoring system is implied. Furthermore, for purposes of this discussion, the term "condition monitoring" is extended to include such scheduled tasks as replacements that are not related to an item's condition but are performed because the required interval has elapsed.

[‡] Milton Kamins, *Quick Fix: Reducing Aircraft Inspection Redundancy Between Base and Depot*, The Rand Corporation, R-1177-PR, April 1973. Marsha Dade, *Examples of Aircraft Scheduled Maintenance Analysis Problems*, The Rand Corporation, R-1299-PR, December 1973.

It has been shown that cost in terms of airframe availability is greater than commonly understood, because in addition to time lost in scheduled maintenance, there is substantial additional loss of airframe availability prior to and immediately after the inspection. Empirical evidence is also available that the aircraft reliability is decreased on sorties immediately following scheduled maintenance. Associated with these decreases in reliability are increases in abort rates and increases in man-hours expended on the flight line as well as in intermediate level maintenance. Negative effects of scheduled maintenance are easier to uncover in the data than are its benefits.

SCHEDULED MAINTENANCE REDUCTIONS

The Air Force has recognized that inspection benefits impose their costs in manpower and operational capability, and has extended inspection intervals and reduced their content. The F-4 aircraft, for example, has had a relatively aggressive reduction in *depot level* scheduled maintenance intervals. These intervals, previously set at two years, are now four years for the F-4D and F-4E, three years for the F-4C, and 4.5 years for the RF-4C. In 1972, major scheduled maintenance at *base level* used the Phased Inspection System, wherein one of six unique phases was conducted every 50 flying hours for a full cycle of 300 flying hours. In contrast, today the F-4 is on a Periodic Inspection System. The full cycle time for this "PE" system is 600 flying hours. Under this system, relatively short hourly postflights (HPOs) are done at 100, 200, 400, and 500 flying hours. These HPOs can be performed on the flight line. The aircraft is docked for an extended HPO at 300 flying hours and for a PE at 600 flying hours.* Though the F-4 scheduled maintenance reductions may not be typical, Air Force programs are under way that continue to press for reductions across all aircraft types.

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*Ralph Elwell and Chris Roach, *Scheduled Maintenance Policies for the F-4 Aircraft: Results of the Maintenance Posture Improvement Program*, The Rand Corporation, R-1492-PR, June 1976.

No Negative Effects

It has been observed that extreme reductions in scheduled maintenance resulting from policy changes, as well as reductions that were accidental or took place because of resource constraints, have not been associated with measurable negative operational effects.* This failure to find measurable effects for the wide range of reductions experienced is puzzling, and seems to imply that even the longer intervals may be too short, and that perhaps the inspection itself is unnecessary.

Inspection Redundancies

One other explanation for the failure to note negative effects for some of the scheduled maintenance reductions observed is the possible duplication of work between base and depot-level inspections. Thus, if reductions in work at one level of maintenance occur without simultaneous reductions at the other level, the aircraft continues to be protected by the surviving set of inspections. As a matter of fact, considerable redundancy has been observed between base and depot-level inspections.†

Scheduled and Unscheduled Maintenance Redundancy

The verified observation about the redundancy between depot and base level inspections did not seem to provide adequate explanation for the failure to note negative effects when very extended inspection intervals were observed. The hypothesis was then raised that perhaps there is a redundancy between scheduled and *unscheduled* maintenance at base level. Under this hypothesis, *items requiring inspections at certain intervals in scheduled maintenance are performed informally (informal condition monitoring by maintenance personnel) at adequate frequencies in the course of doing unscheduled maintenance*. The potential duplication of scheduled and unscheduled maintenance is the central

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*I. K. Cohen, *Aircraft Planned Inspection Policies: A Briefing*, The Rand Corporation, R-1025-PR, June 1973, and Theodore S. Donaldson, *A Study of IRAN Effectiveness for the F-106*, The Rand Corporation, R-755-PR, October 1971.

†Kamins, *Quick Fix*.

concern of this study. More precisely, the central concern of this study is to examine the extent to which the *opportunity* exists in unscheduled maintenance to perform condition monitoring that potentially could preclude the requirements for further scheduled maintenance.

The notion that in the course of accomplishing unscheduled maintenance, "all" (many) areas are, in fact, condition monitored by maintenance personnel so as to be redundant with "all" (many) scheduled maintenance requirements is reinforced, because it appears that this kind of redundancy is not typically considered in setting up inspection requirements.[*]

Judging Items that Should Be Inspected

A number of protocols have been suggested and used for judging whether an item should be inspected. The decision logic provided by MSG-2[†] is currently being used by the Air Force. MSG-2 uses a decision tree approach to facilitate the definition of scheduled maintenance tasks having potential effectiveness. It is believed that it is consistent with the philosophy of such protocols that scheduled inspections be accomplished by condition monitoring[‡] by maintenance personnel if it can be shown that such condition monitoring would occur at the required frequencies.

THE F-4 STUDY

The F-4 is especially convenient for this study because many inspection tasks are located in areas behind fairly small aircraft doors, and we can assume that once the door is removed the opportunity for inspection exists when work in the immediate area of the inspection

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[*] In fact, there are instances in which inspections are requested on items solely because of a high "failure rate" (i.e., maintenance action rate), yet under this condition the item *is* frequently observed.

[†] R&M Subcommittee, *Airline/Manufacturer Maintenance Program Planning Document MSG-2*, Air Transport Association of America, Washington, D.C., March 26, 1970.

[‡] Some readers may object to the use of the term "condition monitoring" for this kind of activity. If so, the process of maintenance personnel detecting reductions in failure resistance during unscheduled maintenance when the aircraft is in some state of disassembly may be substituted for the term "condition monitoring."

task is under way. Not all inspection items located in the interior of the aircraft are behind doors, however, and some require removal of the seat, launchers, and other equipment for access. Many of the items are located in the exterior of the aircraft and are readily visible. This study focuses on inspection tasks behind aircraft doors; other interior and exterior items are *not* included. Accessibility for condition monitoring is defined as the *frequency of door openings*, which is determined by the frequency of maintenance actions on either the door Work Unit Code (WUC) or on WUCs behind the door.

The theoretical notion pursued here is that unscheduled maintenance affords the opportunity and accessibility to perform Periodic Inspection tasks at the flight line. It was found that a large number of Periodic doors are opened on every sortie (some before and after every sortie), and in some cases, these doors did not have a high incidence of unscheduled maintenance activity behind them. In the study results, these flight-line-inspected doors with low unscheduled maintenance activity are counted as high-visibility doors. While this may appear to violate the major theme concerning scheduled-unscheduled redundancy, it seems even more misleading to count these doors as having low visibility when they are so frequently opened. In any event, their inclusion has only a small effect on results, as discussed in the following section.

Section II presents the details of the study design and the data base used to explore the hypotheses of this investigation. Results are presented in Sec. III. Section IV, "Conclusions," explores the implications of the results for Air Force policies regarding aircraft inspection.

II. DATA BASE AND STUDY DESIGN

Several years ago, an initial study was undertaken to determine the extent of accessibility for condition monitoring, using F-4 aircraft data from a sample of 189 aircraft over an 18-month period, although most aircraft were not in the sample the entire 18 months. The results of this initial study were not published because of a number of uncertainties about the data.

To resolve these uncertainties, a second and smaller sample (49 F-4D aircraft for one month) was recently studied. In addition to AFM 66-1 maintenance data, Aircraft Flight Data Record (AFTO Form 781) data were also collected. This record contains door removal data not found in 66-1. The sortie record from the 781 also contains takeoff and landing times, and this information, in conjunction with AFTO Form 349 start and stop job times, was useful in reducing errors that might occur from using only 66-1.

The aircraft sample for the first study contained C, D, and E series F-4s under the Phased Inspection Policy, but the sample for the second study contained only the D series under the Periodic Inspection Policy. A number of doors opened under the Phased policy are not opened for the Periodic policy, and some doors have been added to the Periodic that were not opened in the Phased policy. The present study analyzes only doors opened during Periodic Inspections, and data from the first study have been organized to reflect the Periodic policy, not the Phased policy under which the aircraft were actually inspected.

Inspection tasks performed at the 600-hour Periodic and the 300-hour postflight inspections are described in Air Force Periodic Inspection Decks IF-4C-6WC-6 and IF-4C-6WC-7, respectively. Some of these tasks are on the exterior of the aircraft or require removal of access doors or other aircraft components for inspection. The number of tasks in these locations is shown in Table 1. Numbers are only approximate and vary somewhat as a function of aircraft series and configuration. Inspection items behind doors and on the exterior of the aircraft comprise 78% of all items for the 300-hour inspection, and 76% for the 600-hour inspection.

Table 1

LOCATION OF INSPECTION TASKS

	Location	Inspection 300 Hour		Inspection 600 Hour	
	Exterior	40	78%	110	76%
Interior	Behind Doors	100		139	
Interior	Other Interior	20		58	
Interior	Ejection Seats	20 (in shop)		20 (in shop)	
	Total	180		327	

In each study the total number of removals (hits) for each aircraft door was counted for all aircraft in the sample; then a probability model was used to estimate the probability that a door is opened in any given inspection interval (in this case the 600-hour PE and the 300-hour HPO). It was necessary to use a probability model to determine door removal probabilities per inspection interval because few aircraft remained in the sample long enough (relative to the inspection interval) to use a strictly empirical model, e.g., mean door removals per interval. The model translates mean door removals per flying hour to mean removals per inspection interval. The appendix presents the model in detail and addresses the plausibility of underlying assumptions. Because most of the hardware items in the inspection card decks have essentially random failures, and because failure rates change only slowly over time, the model is based on the constant failure rate approximation.

The data used to determine door removals (hits) in both studies are described below.

FIRST STUDY

In the first study, aircraft flying time and number of sorties were determined from AFM 65-110 data, and actions on WUCs were determined from AFM 6601 data. The approach was to determine the number of unscheduled maintenance actions by WUC, then to identify WUCs behind inspection doors so that actions could be related to door removal.

The maintenance data (AFM 65-110 and AFM 66-1 data) were obtained from George AFB covering a little over 18 months (approximately January

1970 to June 1971) and containing 595,066 maintenance actions. Only maintenance actions that were related to fix actions on aircraft systems 11 through 99 were important; support general actions and the look phase of inspections were omitted. Also, since remove (P code) and replace (Q code) actions generate two cards for a single door removal, the P cards were removed from the sample.

These considerations reduced the data to 232,785 actions against 3,451 WUCs. Table 2 summarizes the number of these actions by aircraft type in terms of actions per flying hour and per sortie. Differences between the C and D series aircraft in actions per flying hour (5.0 and 4.5 for the C and D, respectively), and actions per sortie (7.5 and 6.8, respectively) are small. The E series, however, shows substantially fewer actions per flying hour (3.0) and per sortie (4.6). The effect of pooling data across aircraft series causes the average number of actions to be slightly too low for the C and D aircraft, and too high for the E. Therefore, the data were consolidated into two sets, one for the F-4Cs and Ds and one for the F-4Es.

Air Force personnel at Hill Air Force Base identified all WUCs behind inspection doors so that the maintenance actions could be related to an area accessed by an inspection door. As Table 3 shows, 53,468 maintenance actions were identified as out-of-dock (flight line) on WUCs behind aircraft doors and on the doors. There were 7,830 actions on and behind doors in the dock, but these are not of concern here. This does indicate, however, that a relatively high proportion of all inspection door removals occur at the flight line.

Table 2

AIRCRAFT MAINTENANCE ACTIONS (MA), FIRST STUDY

MDS	Number of Aircraft	MA (11-99)	Flying Hours (FH)	Sorties (SRT)	Average MA/FH	Average MA/SRT
C	73	114,102	22,619.4	15,296	5.0	7.5
D	18	8,052	1,805.7	1,189	4.5	6.8
E	93	110,631	36,908.1	24,018	3.0	4.6
Total	189	232,785	61,333.2	40,503	3.8	5.7

Table 3

NUMBERS OF ACTIONS BEHIND DOORS AND ON DOORS

MDS	Out-of-Dock Actions	In-Dock Actions	Total
F-4C and D	31,598	4,256	35,854
F-4E	21,870	3,574	25,444
Total	53,468	7,830	61,298

These data are used in the probability model (Appendix) to determine inspection item visibility or the probability of panel removal. However, several factors must be taken into account to determine door hit frequencies:

- There is some indication from previous experience that either the door opening or the WUC repair is recorded, but not both.
- More than one maintenance action can occur behind a single panel removal.
- Most right-side and left-side doors that are identical on the aircraft have been assigned the same WUC. Thus, each recorded hit could represent removal of one or of both doors.
- Some doors are installed in tandem and must be opened sequentially. Hence, removals may be recorded on all doors that must be opened or the removal may be recorded only on the last door.
- Some doors are not coded. Their removal on the flight line is either not recorded or recorded as an NOC (not otherwise coded) number.
- A door removal need not be recorded if the removal time is less than 0.1 min.

It appears possible to remove some of the recording uncertainties and inaccuracies by assuming that if a door removal is recorded, the WUC behind it is not, and vice versa. Actually, both *should* be recorded. This assumption was tested by examining a small sample (3 F-4Cs, 2 F-4Ds, 2 F-4Es) of the aircraft in the test data in detail to determine how

often *both* door and WUC are recorded. The results indicate that recording of both door removal and WUC behind it is not a common occurrence (and, in fact did not occur in the sample) and only a small error is introduced by adding these events as if they were independent. This was also checked in the second study, and again did not happen in the entire sample. Thus, the frequency of door hits can be obtained by adding the major contributors: hits on the doors and hits on the WUCs behind the doors.

The possibility of several actions per single door removal is potentially serious, and one that proved impossible to determine in the large sample.

Maintenance actions on WUCs that are found behind both right-side left-side doors (or, in general, behind more than one door) were divided between both (or all) doors. A single action, in this case, would be counted as 1/2 for each door (or 1/k if the WUC is found behind k doors).

Doors not coded were omitted from the analysis and tandem door hits were added together. These are indicated in the following section.

The primary purpose of the second study was to resolve some of the uncertainties that remained in the data of the first study.

SECOND STUDY

Maintenance data were obtained on 49 F4-D aircraft at Holloman Air Force Base for the month of November 1976. Aircraft were selected randomly, except that those transferring in or out during November were excluded, and so were those that had spent any part of the month in Periodic or depot inspections. Data were obtained from the usual MDC 66-1 tape, and also from the Aircraft Flight Data Record AFTO Form 781 maintained by the crew chief, which is reported to contain all door removals. This turned out not to be true, although many door removals were recorded there that were not in the MDC data. Personnel from the inspection dock reviewed the Form 781 records for the 49 aircraft for the month of November and indicated all panel removal actions and notations.

Maintenance actions from the MDC data were generated and related to aircraft doors as decribed in the last section; then these and the

Form 781 records were sorted into sequence by data and aircraft serial number. By observing both the Form 781 (including flying information) and the MDC data simultaneously, it was possible to determine which door was opened in those cases where WUCs are behind more than one; in particular, the right-left door uncertainty was removed. Also, the Form 781 record shows the date that action was initiated (door removal) and the date it was completed (door replaced), so that it was possible to identify multiple maintenance actions per single door removal--that is, work on more than one WUC behind a panel. This would have led to counting multiple door hits in the first study because hits on WUCs were counted as removals. Although time-consuming, a small sample of highly reliable data was derived which contained few, if any, of the uncertainties of the first sample.

The Holloman data are summarized in Table 4. The F-4D in the first study had 4.5 maintenance actions per flying hour compared to 5.5 in the second; it had 6.8 actions per sortie in the first compared to 6.0 in the second. Thus, in the second study, actions per flying hour have increased, while actions per sortie have decreased. This is most likely due to a recent TAC reduction in training sortie length* while holding total flying hours constant, and does not represent any substantial difference between the aircraft in the two studies.

Table 5 shows the number of door removals determined from the 781 data and from the combined 781/MDC data. It is apparent that the MDC data show many door removals not recorded in the 781 record, and that aircraft visibility cannot be inferred from 781 data alone.

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*The flying hour result is consistent with findings in other stuies indicating that failures per flying hour increase as flying hours per sortie decrease. T. S. Donaldson and A. Sweetland, *The Relationship of Flight Line Maintenance Man-Hours to Aircraft Flying Hours*, The Rand Corporation, RM-5701-PR, August 1968; and Maurice B. Shurman, *Time Dependent Failure Rates for Jet Aircraft*, 1978, The Institute of Electrical and Electronic Engineers, Inc., *Proceedings 1978 Annual Reliability and Maintainability Symposium*. Further, the finding indicating a reduction in actions per sortie is consistent with the findings of T. F. Lippiatt, *An Evaluation of the USAFE Tactical Aircraft Maintenance System Test (SALTY TAMS) at Hahn AB: A Briefing*, The Rand Corporation (to be published).

Table 4

AIRCRAFT MAINTENANCE ACTIONS (MA),
SECOND STUDY

MDC	F-4D
Number of aircraft	49
Maintenance actions (MA)	6199
Flying hours (FH)	1134
Sorties	1022
MA/FH	5.5
MA/sorties	6.0

Table 5

DOOR REMOVALS, SECOND STUDY

Aircraft	F-4D
Form 781 removals	271
Total removals	859

III. RESULTS

The sample for the first study includes aircraft series F-4C, D, and E, while the second study contains data only on the F-4D. Since the C and D were found to have substantially higher failure rates than the E, between-study comparisons were confined to comparisons between the second study's D series data and the pooled C and D data from the first study. Results for the F-4E are presented separately.

F-4C AND D

This section presents door hit data for the F-4C and D and compares data from the first and second studies. The comparisons are presented as a check on data accuracy; the primary focus of results is on door hit probabilities within inspection intervals. Although the first study was based on data during a 450-hour, 6-part, phased inspection policy, the data are related to the new 600-hour Periodic policy and associated doors.

Table 6 lists the door hit probabilities for 81 inspection doors. For the first study, the column headed "hits" indicates the total number of door removals as determined by the procedures discussed previously. The column headed "other hits" indicates door removals that are included in other removal actions and not coded against the indicated door.* For example, door 7 is a small door located in door 6L, so that removal of 7 and the latter would not be recorded; the total hits for door 7 is thus 0 (recorded for number 7) plus 470 (for door number 6L). The column headed "adjusted hits" is the sum of "hits" and "other hits." A blank in this column indicates that "adjusted hits" and "hits" are identical. Some doors are removed for pre- and/or post-flight inspections, or at aircraft launch, and these are indicated in this column with an asterisk. The final two columns show door removal probabilities for 300- and 600-hour inspection intervals. A 1.00 in this column means only that the probability of removal is greater

*This includes doors that are contained within larger doors, and tandem doors removed together.

Table 6

PROBABILITY OF DOOR REMOVAL FOR F4-D (AND C) AIRCRAFT

	First Study (F4-C/D)					Second Study (F4-D)				
Door[a]	Hits	Other Hits[b]	Adjusted Hits	Probability of Hit 300 Hr	Probability of Hit 600 Hr	281 Hits	Total Hits	Adjusted Hits	Probability of Hit 300 Hr	Probability of Hit 600 Hr
-1	5856			1.00	1.00	0	181.00		1.00	1.00
-3R	63			* 1.00	1.00	9	10.00		* 1.00	1.00
6L	470			1.00	1.00	4	10.00		.93	1.00
-6R	482			1.00	1.00	9	19.00		1.00	1.00
7	0	6L	470	1.00	1.00	0	0	10.00	.93	1.00
9L	307			.97	.99	6	24.00		1.00	1.00
-15	62	22	1649	* 1.00	1.00	0	3.00	53.00	* 1.00	1.00
-16	1042			* 1.00	1.00	2	18.50		* 1.00	1.00
21L	21			.26	.46	1	2.81		.53	.77
21R	77			.60	.84	2	4.81		.72	.92
-22	1587			* 1.00	1.00	33	50.00		* 1.00	1.00
-23	194			* 1.00	1.00	0	14.20		* 1.00	1.00
-24L	99			* 1.00	1.00	0	1.00		* 1.00	1.00
-24R	77			* 1.00	1.00	0	2.60		* 1.00	1.00
-26L	83			* 1.00	1.00	0	1.00		* 1.00	1.00
-26R	94			* 1.00	1.00	0	1.00		* 1.00	1.00
-29L	48			* 1.00	1.00	2	2.00		* 1.00	1.00
-29R	48			* 1.00	1.00	0	0		* 1.00	1.00
-30L	91			.67	.89	1	3.50		.60	.84
-30R	101			.71	.92	2	3.50		.60	.84
33L	39			.38	.62	2	3.27		.58	.83
33R	25			.26	.46	0	1.00		.23	.41
-34	201			* 1.90	1.00	13	29.81		* 1.00	1.00
-39L	206			* 1.00	1.00	3	9.41		* 1.00	1.00
45	131			.80	.96	1	8.50		.89	.99
51	64			.54	.79	0	6.00		.80	.96
-60	75	61	175	.88	.99	2	4.00	11.50	.95	1.00
61	100	60	175	.88	.99	3	7.50	11.50	.95	1.00
63	179			.89	.99	5	8.25		.89	.99
-64	253			* 1.00	1.00	8	9.00		* 1.00	1.00
-65	281			* 1.00	1.00	7	10.12		* 1.00	1.00
-66L	105	67L	177	* 1.00	1.00	3	3.67	5.48	* 1.00	1.00
-66R	58	67R	83	.65	.87	1	1.50	1.80	.38	.62
72L	161			.86	.98	2	3.60		.61	.85
72R	161			.86	.98	2	2.68		.51	.76
-73L	397	74L	836	* 1.00	1.00	1	8.82	20.34	* 1.00	1.00
-73R	373	74R	788	* 1.00	1.00	0	7.82	17.98	* 1.00	1.00
-74L	439	73L	836	* 1.00	1.00	1	11.52	20.34	* 1.00	1.00
-74R	415	73R	788	* 1.00	1.00	0	10.16	17.98	* 1.00	1.00
75L	276			.97	1.00	0	9.20		.92	.99
75R	326			.98	1.00	0	4.70		.71	.92
-78	189	Launch		* 1.00	1.00	0	5.50		* 1.00	1.00
-80	120	Launch		* 1.00	1.00	0	0.50		* 1.00	1.00
-82L	296	81L	731	* 1.00	1.00	1	7.33	22.63	* 1.00	1.00
-82R	238	81R	674	* 1.00	1.00	4	5.67	18.41	* 1.00	1.00
-83L	593	92L	822	* 1.00	1.00	14	21.08	27.08	* 1.00	1.00
-83R	593	92R	829	* 1.00	1.00	16	37.58	41.58	* 1.00	1.00
86L	161			.86	.98	23	25.50		1.00	1.00
86R	161			.86	.93	20	22.00		1.00	1.00
88L	191			.90	.99	2	10.25		.94	1.00
88R	186			.90	.99	6	12.25		.96	1.00
89L	267			* 1.00	1.00	0	12.33		* 1.00	1.00
89R	299			* 1.00	1.00	0	17.23		* 1.00	1.00
92L	229			.94	1.00	3	6.00		.80	.96
92R	236			.95	1.00	1	4.00		.65	.88
-96L	190	92L	419	.99	1.00	13	17.50	23.50	1.00	1.00
-96R	190	92R	428	.99	1.00	11	16.50	20.50	1.00	1.00
-100L	8			* 1.00	1.00	0	0		* 1.00	1.00
-100R	8			* 1.00	1.00	0	0		* 1.00	1.00
101L	459			1.00	1.00	10	19.50		.99	1.00
101R	459			1.00	1.00	4	17.50		.99	1.00
-102L	425			.99	1.00	5	13.67		.97	1.00
-102R	437			1.00	1.00	3	10.17		.93	1.00
105L	35			.35	.58	0	2.20		.46	.69
105R	37			.37	.60	0	.70		.12	.31
106R	30			.31	.52	0	2.00		.41	.65
109L	87			.66	.88	0	3.60		.61	.85
109R	87			.66	.88	0	3.60		.61	.85
112L	101			.71	.92	0	1.00		.23	.41
112R	71			.58	.83	1	1.25		.37	.60
-118L	8	92L,96L	427	.99	1.00	0	0	23.50	1.00	1.00
-118R	8	92R,96R	434	1.00	1.00	0	0	20.50	1.00	1.00
-119L	8	92L,96L	427	.99	1.00	0	0	23.50	1.00	1.00
-119R	8	92R,96R	434	1.00	1.00	0	0	20.50	1.00	1.00
128L	23			.25	.44	0	1.00		.23	.41
134	464			1.00	1.00	2	18.14		.99	1.00
-135	66			.56	.80	4	10.4		.93	1.00
-138	79			* 1.00	1.00	0	7.00		* 1.00	1.00
-139	83			* 1.00	1.00	0	4.00		* 1.00	1.00
-140	171	82L	993	* 1.00	1.00	1	9.16	31.79	* 1.00	1.00

[a] (-) indicates 300-hour doors.

[b] Numbers represent other doors removed together with the door indicated under "Door" column.

* Indicates pre- or postflight or launch removal. These doors removed on every sortie.

than 0.99 (since a probability cannot actually be equal to 1); and doors with an asterisk in the "adjusted hits" column are automatically assigned a probability of 1.00.

Pre- and/or post-flight inspections are not unscheduled maintenance actions, although they do occur at the flight line and thus provide the opportunity for inspection of Periodic items during normal flight line maintenance. For this reason, doors with an asterisk are counted as high hit probabilities although in some cases the high probabilities are due to flight line inspections rather than unscheduled maintenance. Examination of Table 6 reveals that in the first study a low number of unscheduled hits occurs for only 11 of the 33 flight-line-inspected doors (5R, 24L through 29R, 100L, 100R, 138, and 139); in all other cases, the hit probabilities due to unscheduled maintenance behind these doors are greater than 0.99. Pre- and post-flight inspections therefore do not increase probabilities very much in most cases. We have summarized these data in the following tables, considering asterisked doors as having hit probabilities greater than 0.99. Parenthetically, we point out that 31 of the 46 300-hour Post Flight Inspection Doors are opened on every sortie.

In the second study, the first column of Table 6 indicates the frequency of door removals as determined from the 781 record and the second column indicates the number of total hits adding to those in the MDC data that were *not* in the 781. The other columns are the same as for the first study.

Inspection of the table reveals good agreement between the two studies in terms of probabilities; differences are probably due in most cases to the small sample size of the second study. In some cases (e.g., door number 86R) the 781 hits add substantially to the MDC hit rate, and this accounts for the differences between studies. In any event, there is no reason to doubt the validity of the general magnitude of estimated probabilities.

Both studies indicate that most doors have a high probability of flight line removals between inspection intervals. This is seen more clearly in Table 7, which shows the number of doors with probabilities of 0.99 or greater, and three other intervals of decreasing

Table 7

NUMBER OF DOORS FOR VARIOUS HIT PROBABILITY INTERVALS: F-4C/D AIRCRAFT

Inspection Interval	$p \geq 0.99$	$0.99 > p \geq 0.95$	$0.95 > p \geq 0.50$	$p < 0.50$	Total Doors
300-hour					
1st study	41 (85)	1 (2)	6 (13)	0 (0)	48
2nd study	40 (83)	2 (4)	5 (10)	1 (2)	48
600-hour					
1st study	59 (73)	5 (6)	14 (17)	3 (4)	81
2nd study	59 (73)	3 (4)	15 (19)	4 (5)	81

NOTE: Numbers in parentheses indicate percent of marginal total.

probability. For example, 59 out of 81 doors (73%) in both studies have probabilities equal to or greater than 0.99 for the 600-hour interval.

Table 8 lists the doors that have removal probabilities less than .95 for the 600-hour interval in both studies. These are the doors that might be considered as *not* highly visible, although the 0.95 criterion may be too severe. It is observed in Table 8 that 15 out of 81 doors had low probabilities in *both* studies, and only 21 in *either* study. Even with the rather strict 0.95 criterion, it is obvious that a large majority of periodic inspection tasks are observed (or the opportunity exists for observation) at the flight line.

F-4E (FIRST STUDY ONLY)

Table 9 shows the hit probabilities for the 80 inspection panels on the F-4E.* The format for this table and column explanations are the same as for the first study in Table 6. There are 4 uncoded doors for the F-4E. Comparison with Table 6 makes it apparent that the F-4E has fewer high-probability doors than the C and D series. This can be observed more readily in Table 10.

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*Five doors (642, 3, 4, 7, and 8) are omitted because they are on some, but not all, F-4Es. In addition, doors 141 L/R, 166, 168, 170, and 173, which are unique to the E model, are omitted. At the time this first study was performed, WUCs for these doors were not identified.

Table 8

LIST OF F-4C/D DOORS WITH PROBABILITY
OF VISIBILITY LESS THAN 0.95
IN 600-HOUR INTERVAL

Door Number	First Study	Second Study
21L	*	*
21R	*	*
30L	*	*
30R	*	*
33L	*	*
33R	*	*
51	*	
66R	*	*
72L		*
72R		*
75R		*
92R		*
105L	*	*
106R	*	*
109L	*	*
109R	*	*
112L	*	*
112R	*	*
128L	*	*
135	*	*
Total Doors	17	19

Table 9

PROBABILITY OF DOOR REMOVAL FOR F-4E AIRCRAFT

Door[a]	Hits	Other Hits[b]	Adjusted Hits	Probability of Hit 300 Hr.	Probability of Hit 600 Hr.
-1	10281			1.00	1.00
-5R	24			.18	.32
6L	208			.82	.97
-6R	225			.84	.97
7	0	6L	208	.82	.92
9L	131			.66	.88
-15	57	22	907 *	1.00	1.00
-16	509		*	1.00	1.00
21L	5			.04	.08
21R	21			.17	.31
-22	850		*	1.00	1.00
-23	67		*	1.00	1.00
-24L	72		*	1.00	1.00
-24R	12		*	1.00	1.00
-26L	15		*	1.00	1.00
-26R	9		*	1.00	1.00
-29L	8		*	1.00	1.00
-29R	9		*	1.00	1.00
-30L	28			.20	.37
-30R	39			.22	.47
33L } 33R }	These doors uncoded				
-34	66		*	1.00	1.00
35	4	34	70 *	1.00	1.00
-39L	85		*	1.00	1.00
-39R	72		*	1.00	1.00
-61	103			.57	.81
63	116			.61	.85
-64	177		*	1.00	1.00
-65	211			.82	.97
-66L	86	67L	145 *	1.00	1.00
-66R	38	67R	49	.33	.56
72L	29			.21	.37
72R	29			.21	.37
-73L	189	74L	402 *	1.00	1.00
-73R	182	74R	388 *	1.00	1.00
-74L	213	73L	402 *	1.00	1.00
-74R	206	74R	388 *	1.00	1.00
75L	165			.74	.93
75R	172			.75	.94
78	90	Launch	*	1.00	1.00
-80	42	Launch	*	1.00	1.00
-82L	297	81L	716 *	1.00	1.00
-82R	191			.79	.96
-83L	377	92L	524 *	1.00	1.00
-83R	377	92R	523 *	1.00	1.00
86L	133			.66	.88
86R	133			.66	.88
88L	98			.55	.80
88R	97			.55	.79
89L	175		*	1.00	1.00
89R	173		*	1.00	1.00
-92L	147			.70	.91
-92R	146			.69	.91
-96L	100	92L	247	.88	.98
-96R	100	92R	246	.88	.98
-100L	16		*	1.00	1.00
-100R	16		*	1.00	1.00
101L	113			.60	.84
101R	113			.60	.84
-102L	347		*	1.00	1.00
-102R	192		*	1.00	1.00
105L } 105R }	These doors uncoded				
106R	24			.18	.32
109L	50			.33	.56
109R	36			.25	.44
112L	18			.14	.25
112R	14			.11	.20
-118L	1	92L,96L	248	.88	.98
-118R	1	92R,96R	247	.88	.98
-119L	1	92L,96L	248	.88	.98
-119R	1	92R,96R	247	.88	.98
-122	110			.59	.83
129L	6			.04	.08
129R	6			.04	.08
134	101			.56	.81
-135	13		*	1.00	1.00
-138	16	Launch	*	1.00	1.00
-139	43	Launch	*	1.00	1.00
-140	75	82L	291 *	1.00	1.00

[a](-) indicates 300-hour door

[b]Numbers represent other doors removed together with the door indicated under "door" column.

*Indicates pre- or postflight or launch removal. These doors are removed on every sortie.

Table 10

NUMBER OF DOORS BY PROBABILITY INTERVAL FOR F-4E

Inspection Interval	Probability Interval				Total Doors
	$p \geq 99$	$.99 > p \geq .95$	$.95 > p \geq .50$	$p < .50$	
300	32 (65)	0 (0)	13 (27)	4 (8)	49
600	36 (47)	11 (15)	16 (21)	13 (17)	76

NOTE: Numbers in parentheses indicate percent of marginal total.

SUMMARY OF RESULTS

To summarize the degree of flight line visibility for the F-4 aircraft, Table 11 and Fig. 1 show the percent of all doors that pass selected visibility criteria. Visibility criteria were selected at probabilities of 0.95, 0.90, 0.75, and 0.50, although no policy significance is attached to these criteria. The table shows, for example, that 79% (77% in second study) of F-4C/D doors have a removal probability of 0.95 or greater in a 600-hour interval. Although the E series has less visibility than the C and D, it is apparent that most Periodic Inspection tasks behind doors are observable at the flight line. Comparisons between the first and second study indicate that the probability estimates are quite accurate. It should be noted in passing that, given the F-4E's better reliability (and thus less visibility), this MDS should be evaluated for a greater Periodic interval than the C/D. While administratively it may be cumbersome to have each series on a different interval, the difficulty should ease as the active force comes to consist of the F-4E. If it is determined that a longer inspection interval for the F-4E is appropriate, then the probabilities of F-4E door removals during unscheduled maintenance shown in Table 11 are likely to increase. Such increases would further improve the opportunities for condition monitoring on the flight line for this MDS.

Table 11

PERCENT OF DOORS VISIBLE FOR SELECTED CRITERIA
ON 600-HOUR INTERVAL

	Probability Criteria			
Source	$p \geq 0.95$	$0 \geq 9.90$	$p \geq 9.75$	$p \geq 9.50$
F-4C/D (1st study)	79%	81%	89%	96%
F-4D (2nd study)	77%	79%	90%	95%
F-4E (1st study)	62%	67%	80%	83%

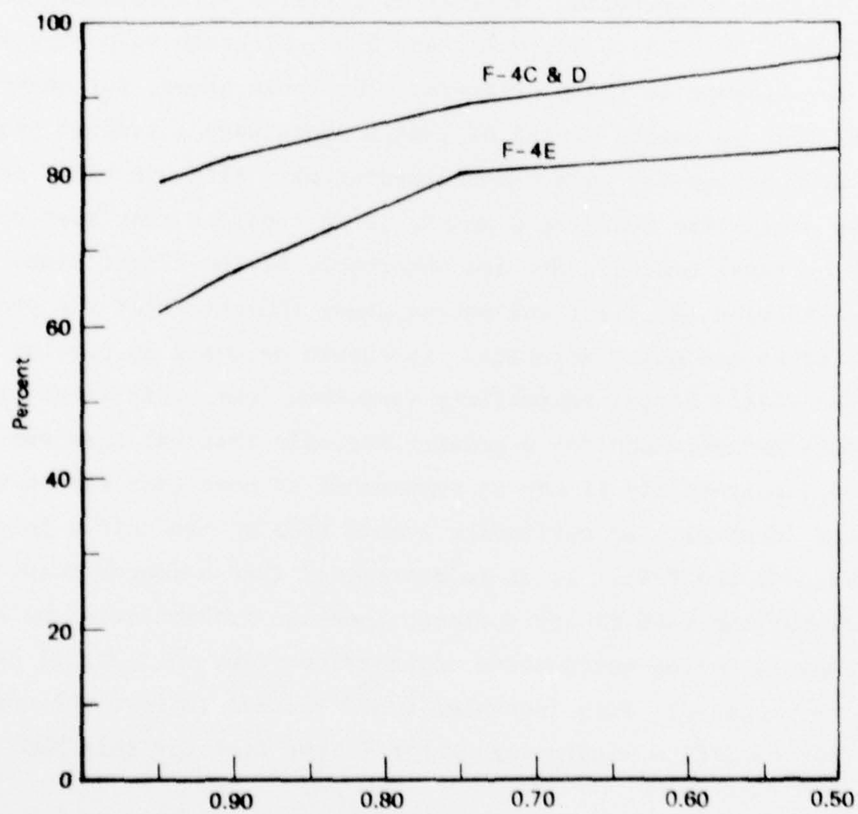

Fig. 1--Percent Door Visibility Versus Probability of Door Hit

IV. CONCLUSIONS

At the outset of this report, we indicated an interest in understanding whether flight line personnel provide redundant protection of air and mission worthiness by performing, during unscheduled maintenance, tasks specified in periodic scheduled inspection requirements, and perform them with equal frequency. This study has shown that many of the F-4 areas of interest to the Periodic Inspection System are indeed accessible for condition monitoring by maintenance personnel on the flight line. Unfortunately, the data cannot tell us the extent to which maintenance personnel actually used the opportunity to perform condition monitoring, but it is not difficult to infer that some of it goes on. The category of "ground discovered discrepancies" in the Maintenance Data Collection system is an objective indication that maintenance personnel do more than respond to discrepancies discovered by aircrews. In addition, this redundancy probably helps explain the observation that aircraft inspections have been extended for considerable periods without apparent aircraft degradation. In any event, there should be some formal way to utilize this unscheduled activity to reduce--perhaps even eliminate--Periodic Inspections.

STUDY IMPLICATIONS

The findings of this study could have important effects on scheduled maintenance policies, sortie production, and readiness, from the point of view of aircraft availability and quality. A full range of options for such exploitation and their evaluation are not within the purposes of this report. However, the remainder of this section identifies a limited set of possible courses. The intent is to stimulate other investigators and the Air Force to explore suitable policies for evaluation and implementation.

The possible actions are to:

1. Encourage an explicit program of condition monitoring on the flight line. Following such implementation, set up a system

for accomplishing some ("all") scheduled inspection tasks in connection with flight line maintenance. This may require modification of existing data systems to facilitate simplified tracking mechanisms to assure adherence to scheduled inspection requirements. Continued need for inspections not susceptible to condition monitoring may be necessary.

2. Include, in protocols used for judging scheduled maintenance requirements, the recognition that maintenance is able to detect "failure resistance" not only in periodic scheduled inspections but also in flight line maintenance when the aircraft is in various states of disassembly.
3. Recognize that the contribution of flight line maintenance to condition monitoring can reduce the risks in extending inspection intervals and decreasing inspection content. The findings reported here lend support to decisionmakers considering proposals for such policy changes.
4. Explore procedures for using the visibility phenomenon within the context of the Production Oriented Maintenance Organization (POMO), because this type of organization appears to be well suited to effecting policies of condition monitoring on the flight line. This is likely to be so because of the role of Crew Chiefs and the proximity of specialists to the aircraft under the POMO.
5. Extend this F-4 analysis to other aircraft types and explore the use of the approach discussed in helping to determine depot level inspection requirements.

Encouraging Condition Monitoring

A potentially worthwhile policy is to explicitly encourage maintenance personnel to perform condition monitoring. Limited situations already exist in which condition monitoring is required. For example, when an engine is removed for maintenance, the engine bay area is condition monitored and corrective action taken for discrepancies found. In this instance, the wisdom of engaging in condition monitoring seems obvious. Policies and procedures need to be developed for extending

requirements for condition monitoring to other areas of the aircraft that become susceptible to monitoring during unscheduled maintenance. The development of a full and effective set of such policies will undoubtedly require considerable analysis and tryout to specify what is to be done, by whom, and under what circumstances. It probably would be useful to separate inspection tasks into a few categories based on the degree to which inspection tasks are similar, or require similar procedures. Categories might include lubrication, calibration, simple look-and-see, tasks requiring further tear-down, and so forth. Decisions within some of these categories probably require tracking mechanisms to avoid underinspection as well as costly overinspection. The danger to be avoided here is the creation of burdensome tracking mechanisms. The frequently occurring, simple, look-and-see tasks may not have to be tracked at all; other tasks might be tracked through the kinds of entries that now occur in the 781 aircraft record; and still other tasks might be tracked periodically through the MDC system on a postaudit basis. To facilitate postaudits through the MDC system to determine the frequency at which certain areas of the aircraft were assessed will probably require some change in rules regarding the documentation of door removals. For a small number of especially critical inspection tasks, it may be advantageous to require the completion of an AFTO Form 349.

Still other kinds of issues are to be resolved in an effective condition monitoring program. In the Tactical Air Forces, the flight line is becoming more and more concerned with the rapid launch and recovery of aircraft, and that trend should not be weakened by a concern for condition monitoring. If an aircraft area has been condition monitored, discrepancies found may have to be written up and deferred for correction at another time. Deferral procedures are becoming more frequent in the TAF. "Quick turn" kinds of requirements are finding such deferrals necessary in order to accomplish the objectives of these fast aircraft turnaround programs. The deferral of some of the burdensome work resulting from condition monitoring appears more desirable than the existing and constraining scheduled inspection programs. Disassembly of aircraft to fix known discrepancies seems a more desirable policy than disassemblies to discover discrepancies.

Reassessing Scheduled Inspection Docking Requirements

Given a working condition monitoring program, the next step might be to pare down scheduled inspections that need to occur in special dockings. Such dockings may continue to be necessary because the frequency of condition monitoring opportunity is insufficient to meet inspection requirements. Of course, an alternative to the docking might be a special inspection requirement placed on the flight line to perform some inspection that they have not accomplished during the normal condition monitoring program. Given defined condition monitoring programs, it also becomes possible to omit certain kinds of inspection requirements. Inspection requirements techniques do typically take into account those items which are monitored by "routine flight crew monitoring." If inspection requirements techniques were to take into account that condition-monitoring by maintenance personnel would occur during unscheduled maintenance, then it is likely that many items which have a very high likelihood of being monitored during unscheduled maintenance would be omitted from scheduled inspections.

Extending Inspection Interval Policies

It may be possible to extend inspection intervals more aggressively so as to reduce the negative effects associated with scheduled maintenance as now practiced, while retaining the benefits of inspection. Extending intervals may be warranted if maintenance personnel are "merely" encouraged to condition-monitor areas opened up during flight line maintenance when convenient to do so. Condition monitoring for special areas of particular concern when extending intervals might be specified as firm requirements.

Especially aggressive extensions might be checked on a programmed basis for negative effects. For example, the F-4E fleet might be divided into quarters, each being assigned a particular interval--say, 750, 900, 1050, and 1200 flying hours. Modest arrangements might be made to assess whether there are differences in aircraft condition as a function of these intervals. To make such policy changes especially useful to combat units, the changeover to the new intervals might be made so that the PE would coincide with a depot visit and could be accomplished during

that visit. This kind of scheduling would reduce the amount of scheduled inspections at base level and reduce base-depot redundancy in scheduled inspections.

Of course, interval extensions might be so aggressive *and depot scheduling might be so effective* as to eliminate the scheduled inspection requirement at base level. In effect, what is now known as Periodic Inspection requirements might become condition monitoring requirements. These requirements could be accomplished routinely and without special tracking mechanisms during unscheduled maintenance. If a small number of items were of critical concern, these might be subjected to requirements for controlled condition monitoring, special inspections, and/or special tracking.

Managing Condition Monitoring

It would probably be more difficult to manage a condition monitoring system under an AFM 661-1 maintenance organization concept than under the POMO concept to which the Tactical Air Forces are transitioning. Under POMO, because specialists are part of the launch and recovery teams, the skills required for condition monitoring are more likely to be close to or at the aircraft.[†] Under POMO, the Aircraft Generation Squadron has extensive responsibility for the work that takes place at the aircraft. The guidance that might be developed for condition monitoring implementation can probably be managed more effectively by POMO Crew Chiefs, since their responsibility for particular serial-number aircraft has increased. Many of the simple tracking systems alluded to above that might be developed to support condition monitoring programs are more likely to succeed if POMO Crew Chiefs control them than if they are managed centrally.

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[*] T. H. Browning (Ogden ALC), I. K. Cohen, and J. Y. Lu, *Costs of the Next Due Base-Level Inspection During a Depot Visit*, The Rand Corporation, R-1865-PR, January 1976.

[†] Of the old Field and Avionics maintenance specialities, all but machinist, welder, sheet metal, fuel systems, egress, sensors, and ECM are now in the AGS.

Extending Study Outcomes

The analysis presented in this report is limited to the F-4 and to inspection items behind doors only. The analysis needs to be extended to items requiring inspections that are not behind doors; and to other weapons, in order to confirm that other promising opportunities for condition monitoring exist elsewhere. Furthermore, this report has focused on the use of condition monitoring to reduce base-level scheduled maintenance requirements; it would be useful to examine the resulting impact on depot inspection requirements.

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Policies such as the foregoing could enhance maintenance quality and could affect, perhaps dramatically, scheduled maintenance policy and practice in the long run. The negative effects associated with scheduled maintenance could be mitigated by an adequate condition monitoring policy and a reduced scheduled maintenance activity. Condition monitoring could free up resources (aircraft and personnel) from Periodic scheduled maintenance and make them available for programs concerned with increasing sortie production. An adequate condition monitoring policy also seems consistent with a NATO type of conventional war, in which it is likely that standing aircraft down for scheduled inspections might be inconsistent with mission requirements.

This study has provided further understanding about the potential redundancy of scheduled and unscheduled maintenance activities. It is likely that, without formal programs, considerable condition monitoring occurs now on the flight line. The extent is unknown. By making the responsibility for condition monitoring explicit, decisionmakers may find it more justifiable to consider aggressive reductions in scheduled activities. It would seem that to be successful, the responsibility for condition monitoring programs should reside in what is known as the Aircraft Generation Squadron under the POMO form of maintenance organization. Guidance and rules with regard to condition monitoring do not now exist. To effect a condition monitoring program will probably take some considerable planning. While the foregoing has covered some illustrative ways for exploiting condition monitoring, these have

been provided for discussion only; they are not a full range of options nor have they been subjected to assessment.

APPENDIX: PROBABILITY MODEL FOR DOOR REMOVAL

The probability model of the visibility study is based on the assumption that, for each aircraft door, the number of door openings in unscheduled flight line maintenance is described by the Poisson process, with time measured in flying hours. Specifically, letting X_t denote the number of times a door on an aircraft is opened during a period in which the aircraft is flown for t hours, we assume there exists a parameter λ, depending on the door, such that the probability distribution X_t is given by

$$P(X_t = k) = \frac{e^{-\lambda t} (\lambda t)^k}{k!}$$

We assume that the parameter λ is identified for the same door on different aircraft.

Theory* tells us that for the distribution of X_t to be Poisson it is necessary and sufficient for the following conditions to hold:

1. The process has *independent* increments. That is, the numbers of door openings in nonoverlapping flying hour intervals are independent.
2. The process has homogeneous increments. That is, the probability of k door openings is identical for all flying-hour intervals of the same length.
3. $\lim_{t \to 0} \frac{P(X_t = 1)}{t} = \lambda$ and $\lim_{t \to 0} \frac{P(X_t > 1)}{t} = 0$

These are equivalent to the statements that (i) for a sufficiently small flying hour interval t, the probability of one door opening during

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*See, for example, Fisz, *Probability Theory and Mathematical Statistics*, John Wiley and Sons, New York, 1963, pp. 276-281.

an interval of t flying hours is λt plus terms of smaller order of magnitude than t; and (ii) for a sufficiently small flying-hour interval, the probability of two or more door openings during a flying-hour interval of length t is of smaller order of magnitude than t. Essentially, then, these conditions are that for a small interval t, the probability of one door opening is λt plus negligible terms, and the probability of more than one door opening is negligible.

Let us assess the reasonableness of these assumptions. The first assumption, concerning independence, would be violated if there were ever a recurring problem with a component under a door, if a problem with one component ever caused a subsequent problem with another component under the same door, or if the repair of a component under a door sometimes itself caused another problem, each circumstance resulting in subsequent door openings related to the first. Such dependence could, for the most part, be taken into account in estimating the parameter λ by simply ignoring all but the first of several door openings occurring in close proximity. This was not possible in the data base of the first study, but in the second study, only one door removal between sorties was counted. The congruence between the two studies indicates that these assumptions are probably realistic.

The second assumption, concerning homogeneity, may be somewhat less reasonable. It assumes that the entire process remains constant over time. It assumes that the frequency of door openings does not depend on the age of the components under the door, the flying hours since last overhaul of these components, the type of flying being done with aircraft, or any other such factor. It also assumes either that the frequency does not depend on maintenance policy or that any maintenance policy on which it does depend will remain unchanged from the period during which the model parameters were estimated to the period in which estimates of the probabilities of door openings are to be utilized. Most of these assumptions could not be checked with the data immediately at our disposal; this would have been a substantial undertaking. In our judgment, however, deviations from these assumptions are not large enough to affect the obtained probabilities seriously.

The third assumption seems very reasonable so long as multiple door openings, while the aircraft is in maintenance, are counted as only single door openings. This would be taken care of automatically by the above-mentioned policy of ignoring all but the first of several door openings occurring close together in time.

The additional assumption that the parameter λ is identical for the same door on different aircraft is essentially the same as the homogeneity assumption, since the probability of a door opening is unlikely to depend on the serial number of the aircraft, but rather on characteristics such as the age of components under the door, the flying hours since overhaul of these components, or the type of operation of the aircraft.

The Poisson model was selected as a simple, approximate, reasonable model of the process. Alternative reasonable models would have been substantially more complex and, typically, could not have been developed with the data at hand.

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The following correction should be made:

Footnote on page 2, change R-1492-PR to R-1942-PR

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